Radiation Calculations for the PD & MI

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Outline

- **Regulatory Requirements**
- **Linac Beam Absorber**
- **Transfer Line Activation**
- **Stripping Foils Area**
- **Injection Beam Absorber**
- **MI Shielding with Proton Driver**

Regulatory Requirements

- **Prompt radiation in non-controlled areas**
  - 0.05 mrem/hr for normal operation
  - 1 mrem/hr for the worst case due to accidents
  - Describe and justify a possible "*credible* worst case accident"
- **Hands-on maintenance**
  - Residual dose rate $P\gamma \leq 100$ mrem/hr at 30 cm from component surface after 100 day irradiation and 4 hrs after shutdown
  - $P\gamma \leq$ 10-20 mrem/hr averaged over all components
- **Ground-water activation**
  - Radionuclide concentration below 20 pCi/ml for ^{3}H and 0.4 pCi/ml for ^{22}Na.
- **Radiation damage to epoxy, cable insulation < 400 Mrad**

Linac Beam Absorber

- **Design goal is to achieve similar radiation levels as at the MI beam absorber**
- **Operating conditions for linac beam absorber:**
  - Accident–the full intensity for 1 hour ($N_{H-} = 5.6 \times 10^{18}$ H^-/hr)
  - Normal operation – $N_{H-} = 3.1 \times 10^{20}$ H^-/year (assuming the ratio N(accident)/N(normal) is same as for the MI absorber)
- **MI beam absorber was designed for 3.26×10^{18} p/yr @ 150 GeV (6.0×10^{16} p/hr for accident)**
- **Linac absorber should have ~one extra foot of steel shielding compared to MI beam absorber**
  - Doses, water activation ~ $E^{0.8}$ at $E > 1$ GeV
  - 1' of steel provides ~ an order of magnitude dose reduction

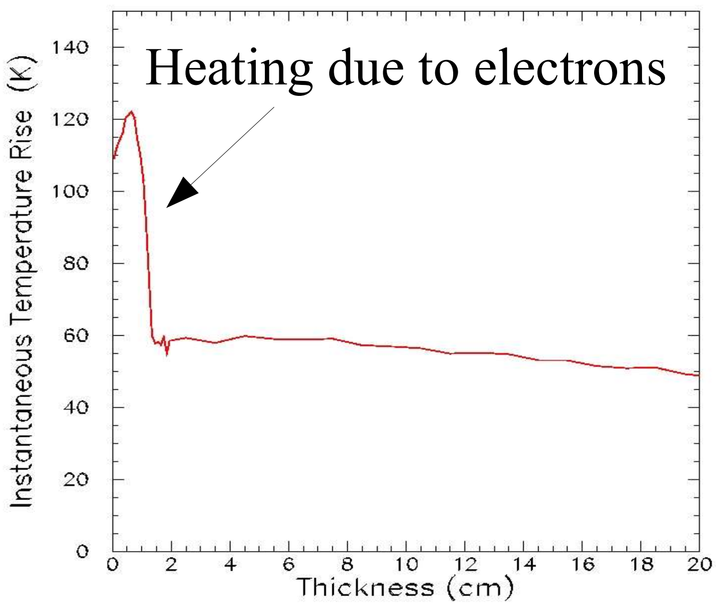
$(3.1e+20\ H^-/yr\ /\ 3.26e+18\ p/yr) * (8\ GeV\ /150\ GeV)^{0.8} = 8.97$

$\Delta x = \log_{10}(8.97) * 1' \approx 29$ cm

Linac Beam Absorber

- **MARS simulations for both the MI and linac absorbers confirmed the estimate**
  - Ground water activation: S_{max}(MI)=0.42 x 10^{10} star/cm^3/yr, S_{max}(Linac)=0.74 x 10^{10} star/cm^3/yr
  - Prompt doses on berm (8 m of soil) for an accident <0.01 mrem/hr
  - Residual dose rates on surfaces of absorbers < 100 mrem/hr

Temperature on Absorber Axis, σ=5 mm



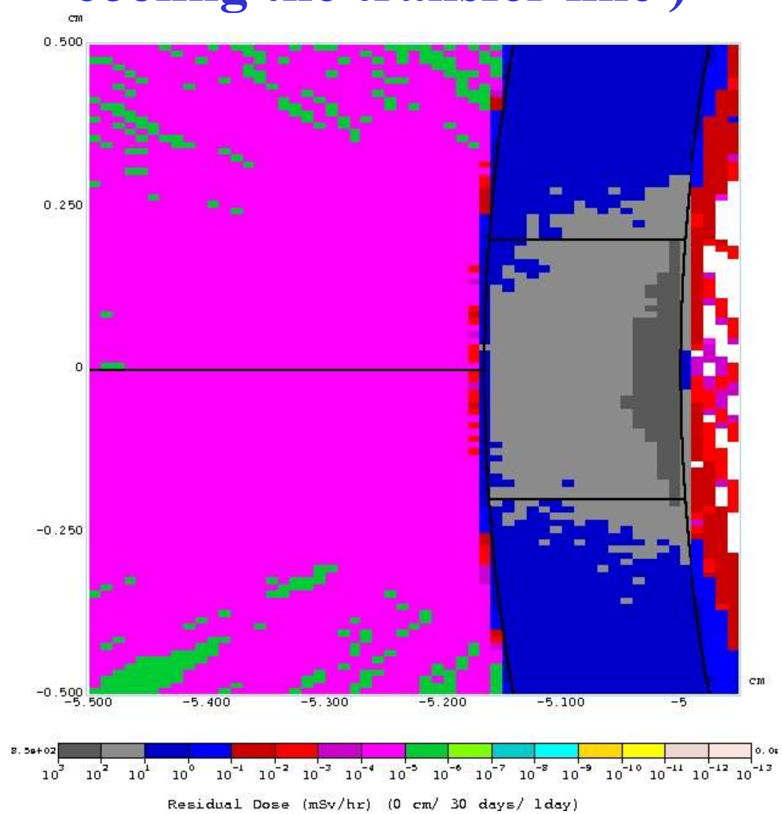
- Beam spot should be large for the absorber to survive one pulse
- One pulse – 200 kJ.
- Maximal beam σ=3 cm
- Temperature build-up may be sizable. ANSYS analysis is needed.
- Cooling must be capable of extracting 2 MW

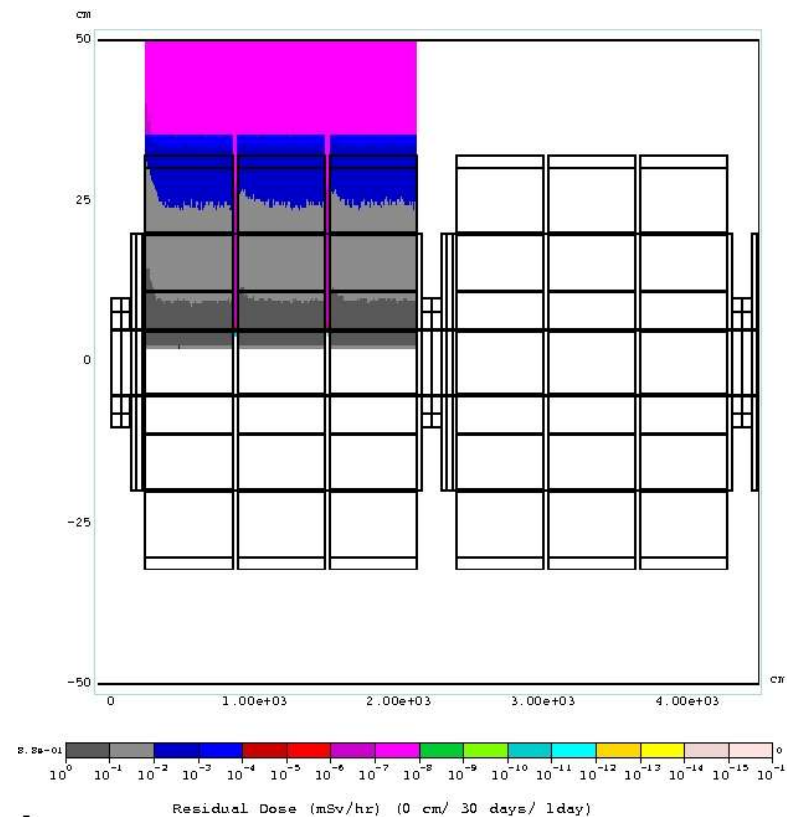
Transfer Line Activation

- **Problem: $H^- \longrightarrow H^0$ stripping due to black body radiation**
- **Losses 0.13 W/m, that is 1 x 10^8 H^0/m/sec**
- **$E_p \approx 8$ GeV, $E_{e-} \approx 4.3$ MeV**
- **Line activation is due to protons**
- **Activation was calculated with MARS**
  - Dipoles and quadrupoles from the Main Ring
  - Protons enter the pipe wall from inside at 2 mrad
  - Vertical Gaussian beam distribution with σ=1 mm
  - Beam is uniformly distributed along the z-axis

Transfer Line Activation

- **Beam pipe: max. residual dose on contact ~ 1000 mrem/hr**
- **Residual dose on magnet surface ~ 10 mrem/hr**
- **There are options to reduce the activation (jaws in dipoles, cooling the transfer line)**





Stripping Foils Area

- **Problem: MI components activation due to interactions in the stripping foils**
- **Activation of the area was simulated with MARS**
  - Two 300 μg/cm^2 carbon foils, size 12x12mm, 40 cm separation
  - One quadrupole, 126 cm from the first foil
- **Two injection schemes were simulated: 90, 270 turns**
- **A proton passes through the foils 4.4 times (90 turns) or 15.9 (270 turns) times on average**
- **Number of protons passing through the foils:**
  4.37 x 10^{14} p/sec (90 turns), 15.9 x 10^{14} p/sec (270 turns)
- **Distributions for H^{-} and protons after stripping were obtained with the STRUCT code and used in the model**

Stripping Foils Area

- **For the 90-turns injection scheme, residual dose averaged over the front surface of the quadrupole is 410 mrem/hr, residual dose on the side surfaces is ~ 40 mrem/hr**
- **For the 270-turns injection scheme, activation is scaled with a factor of 3.6**
- **Peak absorbed dose in quadrupole coils < 100 Mrad/year for the 90-turns injection. Want to keep the total absorbed dose below 400 Mrad.**
- **Options to reduce activation/damage**
  - Local shielding
  - Use of a wide aperture quadrupole

Injection Beam Absorber

- **Not stripped in foils H^0 are stripped in a third thick foil**
- **Protons are dumped onto Injection Beam Absorber**
- **Takes 10 kW of beam power (continuous operation) (I_p=7.8 x10^{12} p/sec), that is ~7.5% of beam power for 120 GeV operation or ~ 1.25 % for 32 GeV operation.**
- **Stripping efficiency for 8 GeV H^- is not known. 10 kW conservatively assumes 500 times more power than in the A. Drozhdin's talk.**
- **Accident scenario – 1 full pulse (1.5 x10^{14} p) is dumped**
- **Design is driven by normal operation not by accidents**
- **MI beam absorber was designed for 3.26 x 10^{18} p/year @ 150 GeV**
- **Injection Absorber takes 1.56 x 10^{20} p/year @ 8 GeV**

Injection Beam Absorber

- **Existing MI beam absorber**
  - 6” x 6” x 2.4 m graphite core
  - 6”-thick Al box, water cooled
  - 0.84 m -thick layer of steel
  - 1.1 m -thick layer of concrete
- **In Injection absorber, steel shield must be increased by ~20 cm**
  - Doses, water activation ~ $E^{0.8}$ at E > 1 GeV
  - 1' of steel shielding provides 10 times dose reduction

  $(1.56e{+}20\ p/yr\ /\ 3.26e{+}18\ p/yr) * (8\ GeV\ /150\ GeV)^{0.8} = 4.59$

  $\Delta x = \log_{10}(4.59) * 1' \approx 20.18\ cm$
- **Core must survive one pulse at the full intensity (200 kJ)**
- **Active cooling for the core is needed.**

MI Shielding with PD

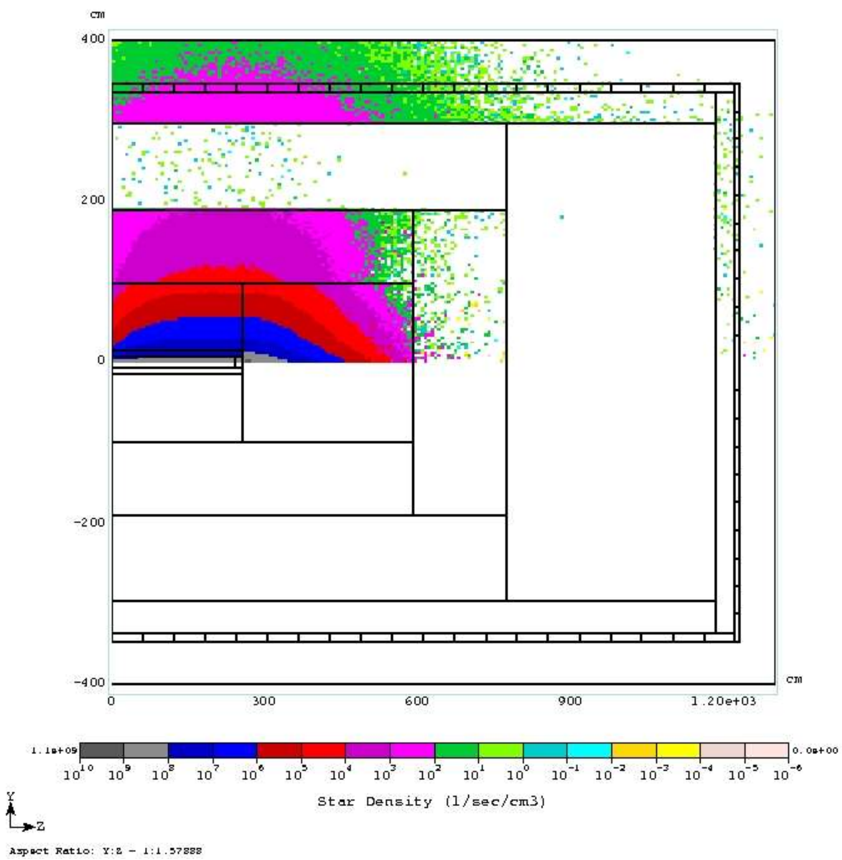
- **Ground water: results of measurements of tritium concentration from 17 locations around MI showed no concentration levels above 0.1 pCi/ml**
- **Air activation: major contribution from short-living isotopes ^{11}C and ^{13}N ($\tau_{1/2}$=20 mins, 10 mins). A 2 hrs delay is sufficient to make access. Currently, the release of activated air is insignificant.**
- **Residual activity: Lambertson magnets and respective kickers are 'hot'. Some of them will be removed.**
- **Shielding: most of the MI berms are classified as "Unlimited Occupancy". With PD, some areas may become "Controlled Areas". New postings can be added to the berms.**
- **The present MI shielding is appropriate for present & future neutrino experiments**

Conclusions

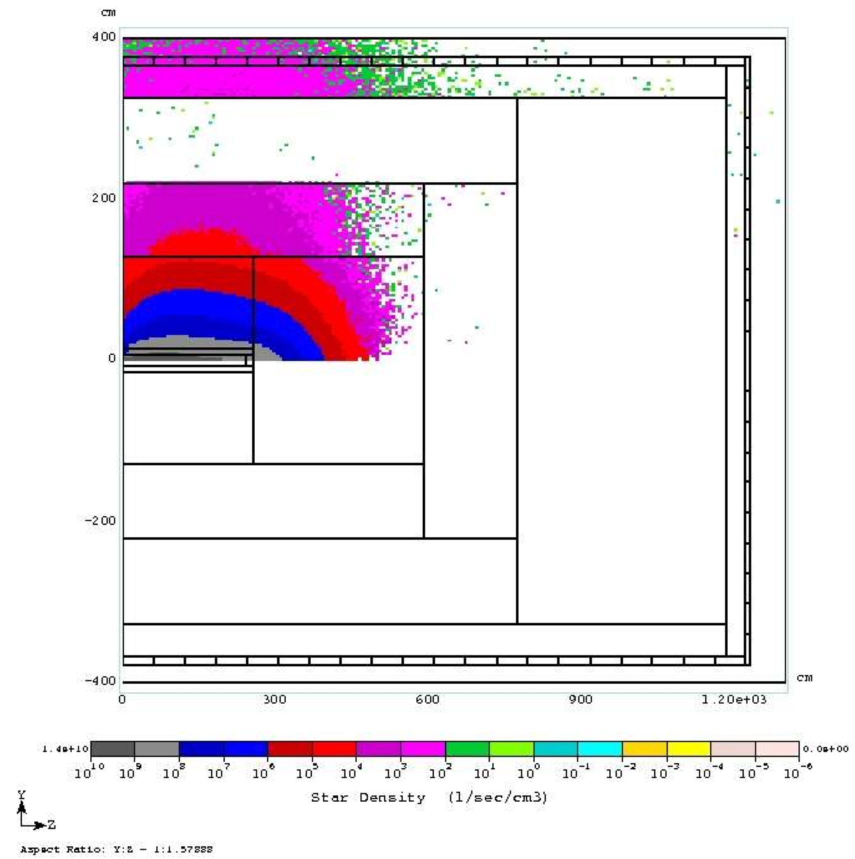
- **Shielding for transport line collimation system has not been designed yet. It will be addressed later.**
- **Currently, no show-stoppers have been found**
- **Use of the same simulation tools and methods, and result benchmarking with other Fermilab projects provide us with a confidence that no radiation related problems are expected**

Backup: Linac Absorber vs. MI

Star density distribution at MI absorber

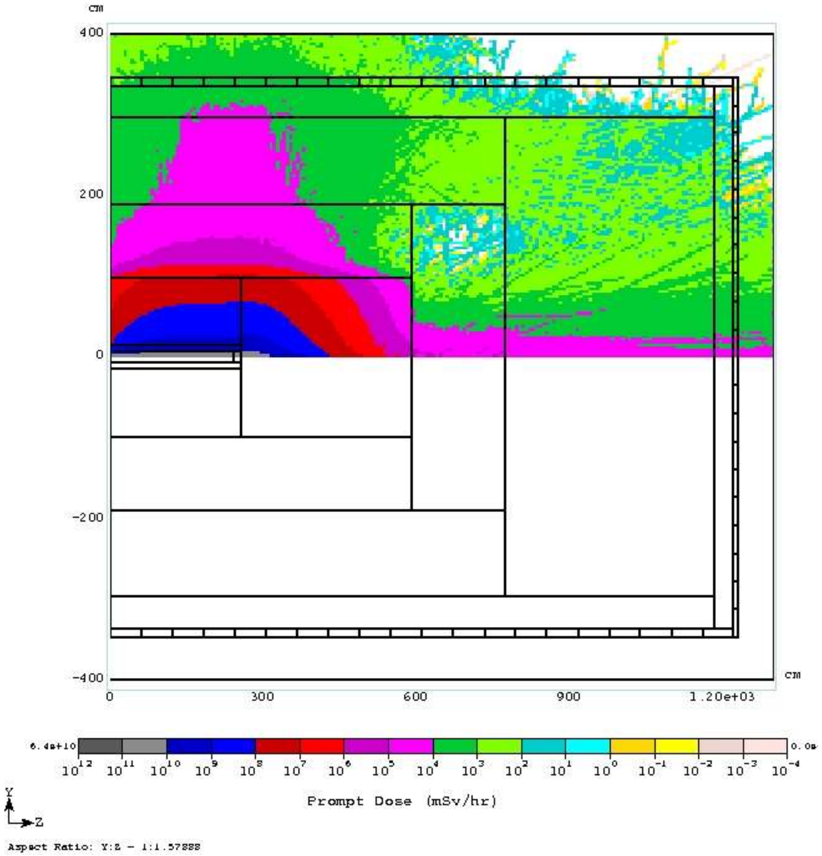


Star density distribution at Linac absorber

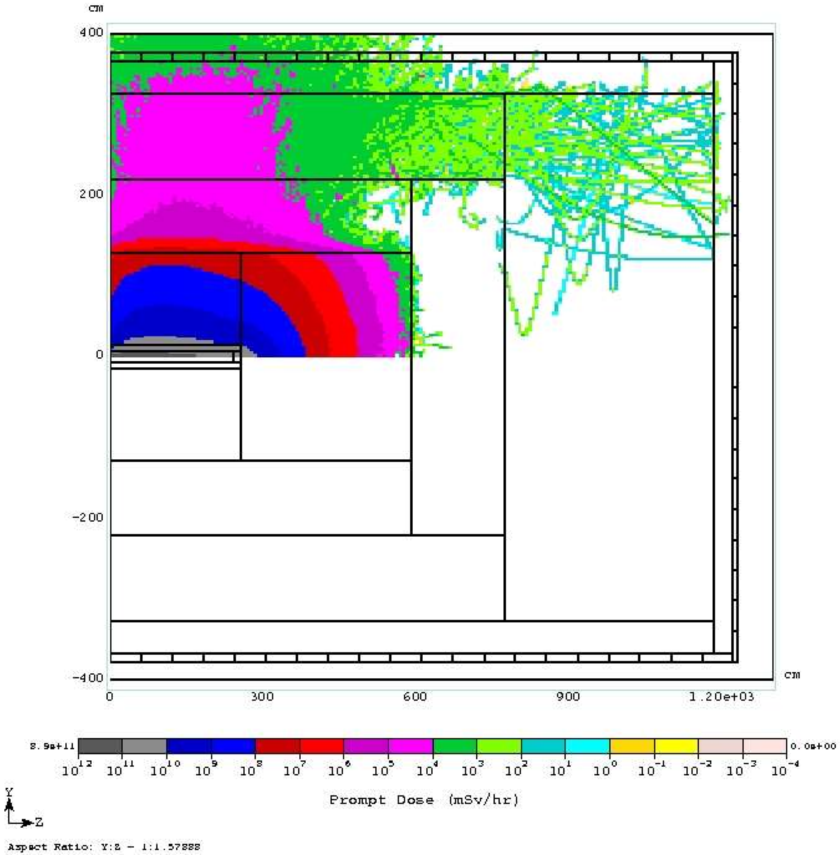


Backup: Linac Absorber vs. MI

Prompt dose distribution at MI absorber

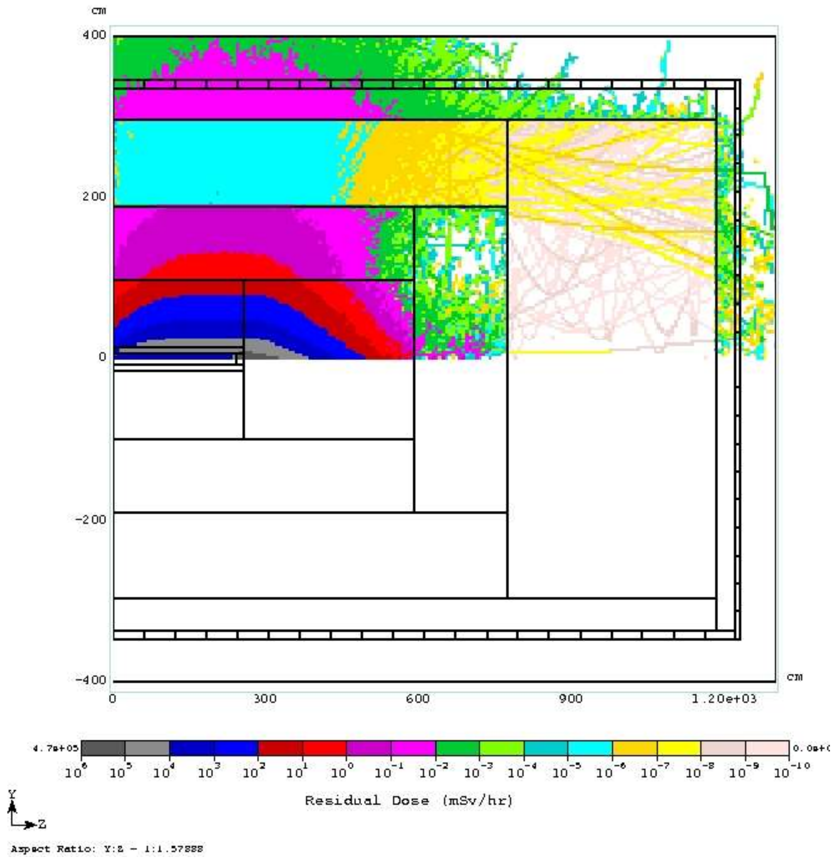


Prompt dose distribution at Linac absorber

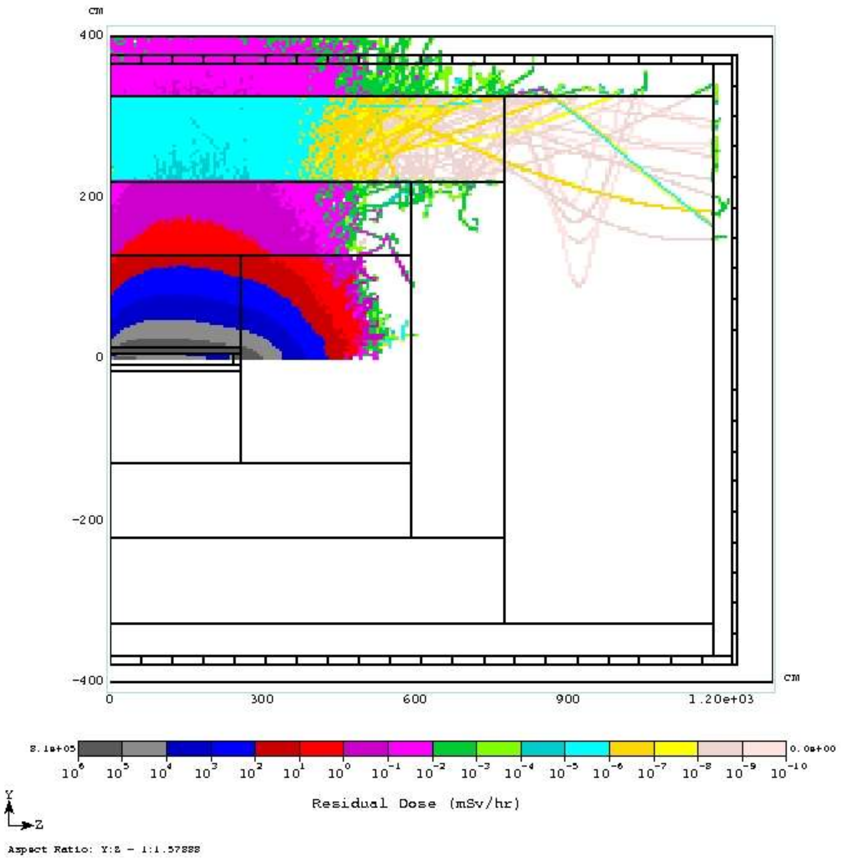


Backup: Linac Absorber vs. MI

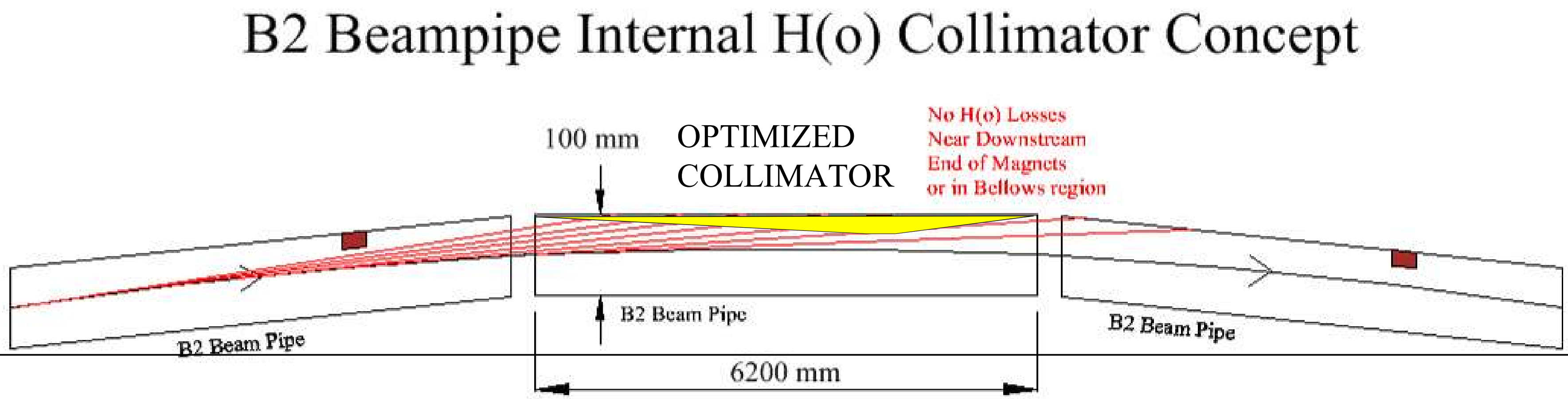
Residual dose distribution at MI absorber



Residual dose distribution at Linac absorber



Backup: Transfer Line Activation



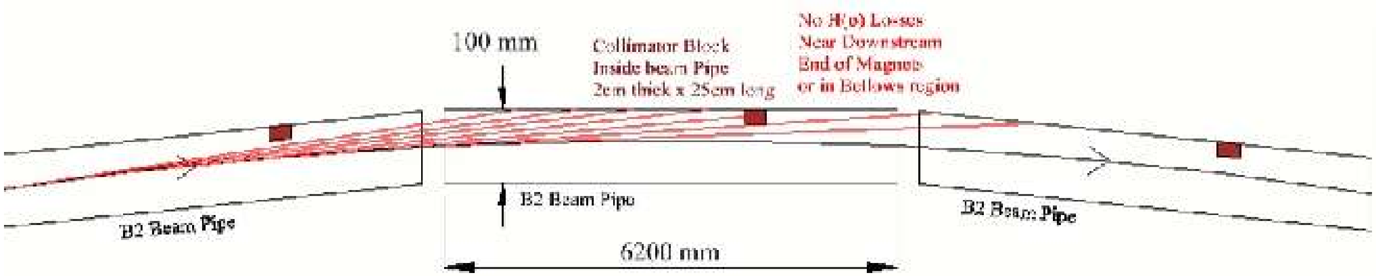
- **The idea of the H-zero collimator is to get the H-zero losses from blackbody radiation to shower up deep inside the body of the magnet, but not in the interconnect region or near the downstream end where it will irradiate the interconnect region.**

- **It doesn't have to be a great collimator – we are only looking for a factor of 5-10 to make the activation of the magnet end regions less of a problem.**

Backup: Transfer Line Activation

Dec. 10, 2004 G.W.Foster

B2 Beampipe Internal H(o) Collimator Concept



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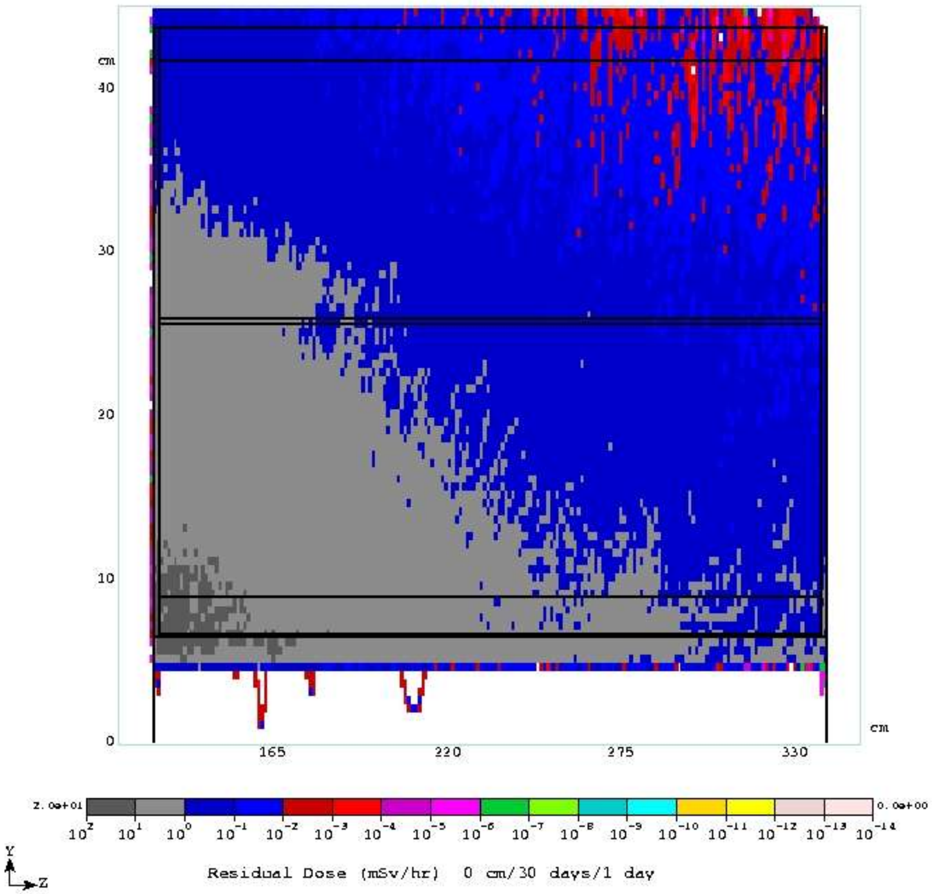
Backup: Stripping Foils Area

Residual activation in quadrupole (90 turns injection). Elevation view.



Absorbed dose in first 30 cm of quadrupole (90 turns). Cross-section view.